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Tool Design for Electronic Product Dismantling

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Abstract

In industrialized countries, waste electrical and electronic equipment is mostly processed in shredder-based processes, which are characterized by a low recovery of precious metals, rare earth elements and flame retardant plastics. To increase the recycling efficiency for these materials, a dismantling tool has been developed. The development process of the dismantling tool was guided by in-depth analysis of the required disassembly time for LCD TVs and laptops. The results of practical experiments demonstrate that the use of the dismantling tool enable to reduce the dismantling time for plastic housing components and PWBs with respectively 36 % and 45 % for LCD TVs.

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Keywords: Dismantling, Disassembly, Recycling, WEEE

1. Introduction

Waste of electrical and electronic equipment (WEEE) is, with an estimated annual growth rate of 3 – 5 %, the fastest growing waste stream [1]. In addition, WEEE contains a complex mix of both hazardous and valuable materials. Therefore, the treatment of this waste stream encompasses several challenges, as well as a substantial potential to reduce both material scarcity and environmental impact caused by mining and refining operations. However, in industrialized countries WEEE is nowadays mostly processed in a fully automated shredder-based process, which is characterized by a low recovery of precious metals (PMs) [2], rare earth elements [3] and specific plastics, such as plastics containing flame retardants (FRs) [4].

At the same time, prior research has demonstrated that the recycling efficiency for PMs, rare earth elements and FR plastics can significantly be improved by systematically demanufacturing end of life (EoL) products [4, 5]. Demanufacturing is defined as the breaking down of products into their components or composing materials in support of all possible combinations of repair, refurbishing, remanufacturing, cannibalization and/or recycling processes [6]. However, prior research has also indicated that, due to high labour costs in industrialized countries, manual disassembly for the purpose of recycling is for most WEEE categories not economically viable [6]. Consequently, in industrialized countries manual disassembly for the purpose of material recycling is only performed for specific WEEE categories for the following three reasons: (1) when required by legislation, for example for the removal of batteries or large capacitors, (2) for the purpose of cannibalization for component reuse and (3) for the separation of Printed Wiring Boards (PWBs) with high concentrations of PMs [7]. To increase resource efficiency in an economically viable manner for both these WEEE categories that are and are not disassembled today, it is essential to reduce the cost of systematically removing the following components:

- PWBs containing PMs
- Electric engines, hard drive and speakers contain rare earth elements in the magnets
- Plastic housing components

The cost of removing these components can be reduced by

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lowering the human intervention during the disassembly process. With this objective, prior research focused on automation of both non-destructive disassembly and destructive dismantling processes for, among others, washing machines [6, 8], personal computers [9], LCD monitors [10-13], mobile phones [14, 15], remote controls [16], digital cameras [17] and End of Life Vehicles (ELVs) [18-20]. However, to date the only examples of automated disassembly or dismantling process that were implemented on an industrial scale are the specific cases of the remanufacturing of single-use cameras and the separation of the funnel and panel glass from Cathode Ray Tubes (CRT) [6]. One of the main reasons for the limited industrial implementation of automated disassembly or dismantling processes is that these techniques require advanced product recognition and intelligent, versatile handling techniques, which lowers the robustness and increases the costs of such systems [10, 17].

At the same time, dedicated hand tools have been developed in prior research for the disassembly and dismantling of WEEE. For example, Zhao et al. have developed a special type of screwdriver which can cut the plastics around the screw in case that the screw is worn out and cannot be unscrewed [21]. Furthermore, Seliger et al. have developed disassembly tools that can generate a new acting surface for a screwdriver, which avoids the need for tool change [8, 22]. The main advantages of such tools are the limited required investment cost and the ease at which these tools can be adopted in existing recycling lines.

Therefore, the presented research focusses on the development of a low-cost semi-automated dismantling tool to enable reducing the time, and accordingly the cost, of systematically removing components of WEEE. To gain insights in opportunities to significantly reduce the disassembly time, an in-depth analysis of the disassembly processes for Liquid Crystal Display (LCD) TVs and laptops is presented in the next section. In the third section, the developed dismantling tool is presented. In the last chapter, the results of practical experiments in which the developed dismantling tool is evaluated for the separation of back covers and PWBs from LCD TVs are discussed. In addition, opportunities to improve both the design of the dismantling tool and the product design to increase the applicability and efficiency of the dismantling process are discussed.

2. Disassembly/dismantling analysis

Within the presented research in total 73 LCD TVs with Cold Cathode Fluorescent Lamps (CCFLs) backlights, which were randomly picked from the Belgian waste stream during the period 2010-2014, were manually disassembled in-depth at a recycling facility. For all these LCD TVS the time required to release and remove the individual components (t) was measured by analyzing video recordings of the disassembly process. The LCD TVs were disassembled by three employees used to perform disassembly activities as part of their job. The disassembly stations included a set of bins for the separated components, one pneumatic screw driver, a set of bits and one wire cutter. The results of these analyses demonstrated that the time required to in-depth manually disassemble LCD TVs varies between 188 s $\leqslant$ t $\leqslant$ 929 s with an average of 479 s and a standard deviation of 174 s. Furthermore, the presented results indicate that the metal frame, which functions as an internal structure for the TV, and the back cover are the most labor intensive components to disassemble, as shown in Figure 1. The presented analyses also demonstrate that in total 20 % of the time is spent on disassembling the PWBs.

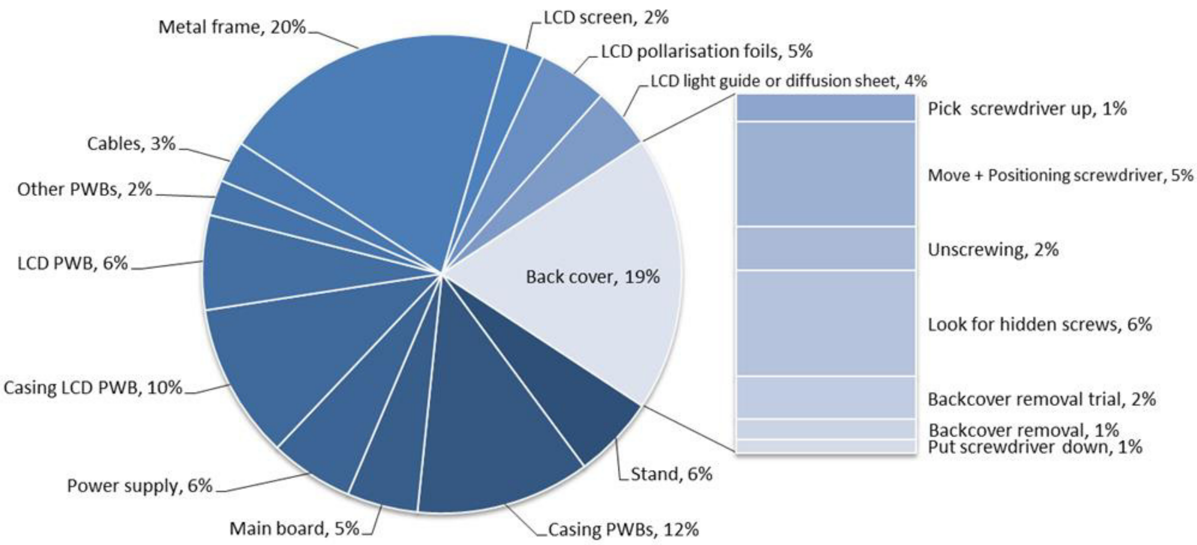


Figure 1 Average manual disassembly time based on the analysis of 73 LCD TVs

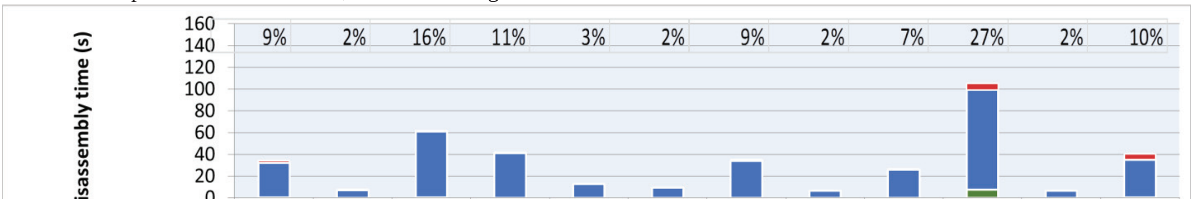
To gain insight into which tasks of the disassembly process are more time consuming, the disassembly time required for removing the back cover was analyzed in depth for 23 LCD TVs, which is shown in Figure 1. For this analysis the disassembly process is split up into 7 steps: (1) grabbing and holding the tool before using it, (2) localizing the fasteners and positioning the tool at the fasteners, (3) disconnecting fasteners, (4) localizing where the targeted component is still fastened, (5) trying to remove the targeted component while it is still attached, (6) removing the targeted component and placing it in a bin (close to the disassembly station) and (7) positioning the tool back in the rack of the disassembly table. Results of these analyses demonstrate that more than 60 % of the back cover disassembly time is required for (i) tool positioning (29 % of back cover disassembly time), (ii) localizing additional screws (30 %) and (iii) unsuccessful trying to remove the back cover while it is still attached (6 %). In addition, within the presented research 49 laptops, which were randomly selected from the Belgian waste stream during the period 2014-2015, were disassembled and dismantled. These laptops were dismantled and disassembled in three workstations by employees performing these activities as part of their daily job. In the first workstation, the screen is separated by placing the laptop on the edge of the table and opening the laptop more than 180 degrees or by using a large screwdriver as a lever. Thereafter the keyboard, top housing cover and the battery are disassembled at the first work station. In the second workstation the hard drive, DVD/CD-player and the motherboard are disassembled. In the third workstation the cooling, Random Access Memory (RAM) and Central Processing Unit (CPU) are disconnected from the motherboard. Based on the performed analysis it is not possible to determine the average disassembly time for an average laptop because: (1) not all laptops contained all components, for example only the old laptops contained a floppy disk, (2) because some components were missing, for example, hard drive and RAM were often missing, most likely because these components were removed for the purpose of data security and/or reuse and (3) not all disassembly times were analysed for all laptops at the three workstations. Nonetheless, an average disassembly time per component could be analysed, as shown in Figure 2. The presented results indicate that the motherboard and the housings of the laptop (bottom cover and inside top cover) are the most labor intensive components to disassemble, as shown in Figure 2.

To gain insight into which tasks of the disassembly or dismantling process are most time consuming for laptops, the time required for tool change, for unfastening and for identifying the position of the fasteners (if this lasts more than 5 seconds) is registered. Results of these analyses demonstrate that most of the time is spent on unfastening and that only for disassembling the motherboard and the connector rail a limited amount of time is spent on tool change and fastener identification. It should be taken into account that the need for tool change is also limited due to the use of three different workstations and that in some cases the remaining connections are destroyed by pulling apart the components instead of spending time on the identification of the remaining fasteners.

3. Dismantling Tool

The performed LCD TV and laptop disassembly analysis demonstrated that the removal of plastic housings and PWBs are two of the most labor-intensive tasks of a disassembly process. The presented results also show that for disassembling LCD TV back covers more than 60 % of the time is required for the identification of the fasteners, whereas only unfastening time has been registered for the removal of the housing of laptops. This difference can be explained by the significantly larger size of housings of LCD TVs compared to laptops, which impedes the identification of the fasteners, and the higher variety of fasteners used in LCD TVs. In consequence, the required disassembly time for LCD TVs can be significantly reduced by improving the visibility of the fasteners, whereas this is expected to only reduce the disassembly time for laptops to a limited extent.

During the performed experiment nearly all screws could be unfastened by unscrewing and severely rusted screws were only encountered in one of the analyzed LCD TVs. In addition, the time required for tool change is limited during both the LCD TV and laptop disassembly processes. Consequently, the potential time savings that can be obtained by the use of the dismantling tools developed in prior research , such as the special type of screwdriver which can also cut the plastics around screws [21] and the disassembly tools which can generate a new acting surface for a screwdriver [8, 22], is also limited.



	Screen	Battery	Inside Top cover	Bottom cover	Hard drive	DVD-player	Floppy disk	RAM	Cooling	Mother-board	CPU	Connect - or rail
Tool change	1.8	0.1	0.3	0.8	0.0	0.0	1.2	0.0	0.8	5.8	0.0	5.4
Unfastening	32.0	7.2	60.9	41.0	12.5	9.6	34.0	6.5	25.9	91.7	6.7	34.7
Fastener identification	0.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.4

Figure 2 Average manual disassembly time analyzed per component based on the analysis of 49 laptops

In contrast, when the need for identifying, as well as the position of a screw driver relative to every individual fastener, could be avoided, this would result in a significant reduction of disassembly/dismantling time for both LCD TVs and laptops.
Therefore, a tool is developed in the presented research, which can be inserted in a design gap or between the front cover and LCD module and pull apart the housing components, as shown in Figure 3. The objective of this tool is to enable to release simultaneously multiple screws, which would avoid of identifying and positioning a tool relative to every fastener and, therefore, allow to lower significantly the required disassembly/dismantling time. To evaluate the applicability and potential time savings of using a tool with this working principle the pneumatically actuated semi-automated tool shown in was developed. To enable to test the tool for the dismantling of a broad range of products and components a robust tool was developed which can exert an adaptable force of up to approximately F = 1750 N to pull apart components and which can be used as a scissor to cut cables with a force of up to approximately F = 1550 N, as shown in Figure 5.

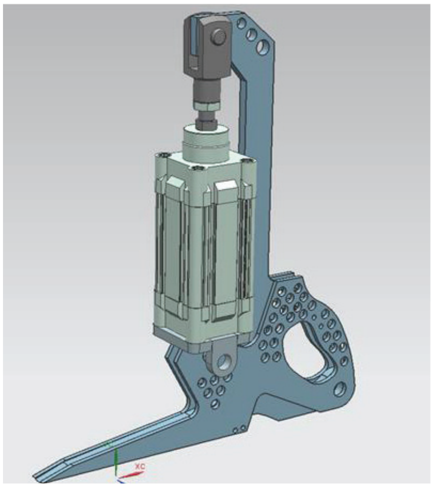


Figure 3 Tool Design for Product Dismantling

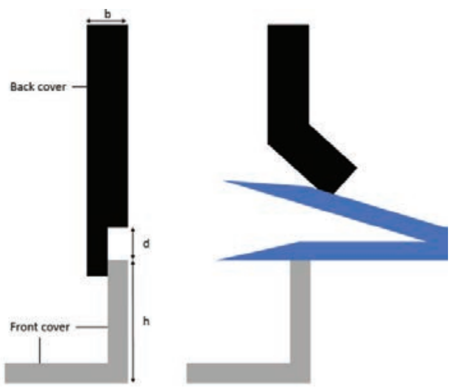


Figure 4 Working principle of dismantling tool

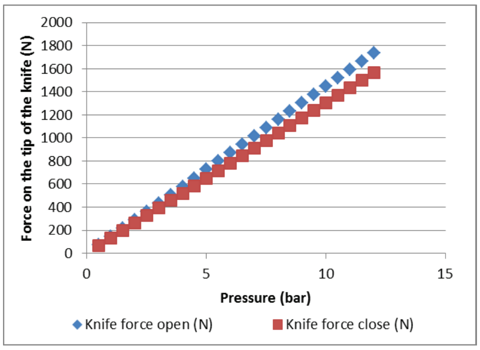


Figure 5 Force that can be applied to pull apart components and to cut cables with the developed dismantling tool in function of the working air pressure

To evaluate the reduction in disassembly time obtained by the use of the developed dismantling tool the front covers of three LED LCD TVs were dismantled in on average 24 s. After removal of the front cover, the unfastening of the screws on the edge of the back cover was no longer necessary, and only a limited number of screws in the centre of the back cover still had to be unfastened to remove the back cover, which was possible to do in on average 52 s. After that, the tool was also used to remove the main board and power supply of the three LED LCD TVs in on average 17 s and 15 s. Furthermore, it was also attempted without success to separate the screen, housing components and motherboard from three laptops with the developed tool.

4. Result and Discussion

The performed experiments demonstrated that the use of the developed semi-automated dismantling tool can allow reducing the disassembly time for plastic housing components and PWBs with respectively 36 % and 45 % compared to the average disassembly time needed for unfastening these components with standard tools, as shown in Figure 6. However, further analysis also demonstrated that the application of the tool has the following limitations: First of all, a sufficiently large design gap or distance between the two components to be separated is needed to be able to place the tool between them. In the case of the three LED LCD TVs used for the evaluation of the tool the front cover could sufficiently be deformed to enter the tool, as shown in Figure 4.
For the dismantling of the PWBs, there was also sufficient distance between the PWBs and the metal plate on which they were mounted. However, the performed disassembly experiments also demonstrated that for many other LCD TVs there is insufficient space to enter the tool for dismantling the plastic housing and the PWBs. In the case of the laptops, the difficulty for the penetration of the tool is also one of the main difficulties impeding the application of the developed tool.
Secondly, the performed experiments demonstrated that the developed tool cannot be used to unfasten metal components connected by screws, because either the force that could be applied with the tool is insufficient or the attached metal components deformed while remaining connected.

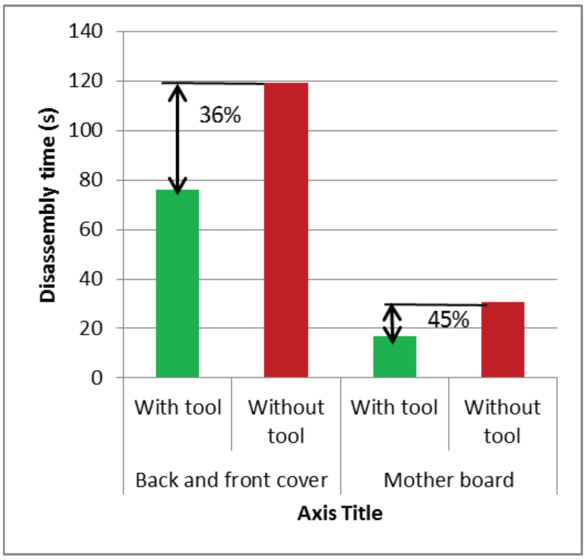


Figure 6 Time savings that can be obtained by the use of the developed dismantling tool

Consequently, the developed tool can only be used for the dismantling of plastic components and PWBs without a metal shielding around it. The inability of unfastening the metal components connected by screws is also one of the reasons why the developed tool cannot be used for the dismantling of laptops that often contain several metal structures on which the PWBs are mounted.

Finally, another limitation of the use of the developed tool is the fact that also plastic housing components can sometimes deform to a large extend before the screws with which they were attached are torn out. In consequence, the housing components sometimes have to be pulled apart while repositioning the tool closer to the remaining fasteners. Alternatively, only the outer connections can be dismantled with the tool and the central screws can be unscrewed, as was done during the performed experiments.

Furthermore, it should also be noted that the developed tool should be used with sufficient care, since with a sudden breakage of one of the components during the utilization of the tool this component can be launched towards the dismantler. For this reason and because of prior discussed limitations, the authors believe that the developed dismantling tool can best be applied to specific products for the dismantling of only plastic components and PWBs in combination with standard disassembly tools in either one or multiple dedicated working stations.

To increase the applicability and efficiency of the developed dismantling tool either or both the tool design and/or the design of the products to be dismantled can be improved. Based on the performed experiments the following, but often contradicting, opportunities for enhancing the design of the dismantling tool are identified:

- Reduce the weight of the tool to improve the maneuverability, for example by using a counter weight
- Increase the force that can be applied with the tool, for instance by using a hydraulic actuator
- Increase the stroke of the tool, for example by increasing the length of the arms
- Facilitate the penetration of the tool in the product, for example by vibrating the tool

Alternatively, electronic products could also be equipped with an opening where such tool could easily penetrate the product. In addition, the design of electrical and electronic products could be adapted in such a manner that the connections could be released with a lower force. Lowering the force at which fasteners can be released may at first glance seem to be in contradiction with the design objective to provide a product with a sufficiently high robustness. However, it should be considered that nowadays many products contain electronic components that require careful handling. In consequence, it makes no sense to design products with fasteners which can resist a force which is a multiple of the forces at which other components start to fail. Moreover, fasteners that release in extreme conditions, but which can be used to reassemble the product, are often preferred over fasteners that retain the assembly during extreme conditions with the risk that specific components are damaged. Taking this into account, the authors have within prior research developed innovative low-cost elastomer-based fasteners, which can be simultaneously released by applying a sufficiently high force over a predefined period of time [23]. The concept behind these elastomer-based fasteners is that they will not release but only deform to a limited extent during a product drop, since the elastomer will absorb the released energy. When a force is applied over a longer period of time, for example by using the developed dismantling tool, these elastomer-based fasteners will deform and subsequently release. Accordingly, the implementation of these fasteners will also increase the applicability and efficiency of a dismantling process with the developed tool.

5. Conclusions

To gain insights in opportunities to significantly reduce disassembly time, an in-depth analysis of the disassembly processes for Liquid Crystal Display (LCD) TVs and laptops is performed. Results of these analyses demonstrate that the disassembly time for LCD TVs can be significantly reduced by improving the identifiability of the fasteners, whereas this is expected to only reduce the disassembly time for laptops to a limited extent. Therefore, a tool is developed in the presented research, which enables to release simultaneously multiple screws by pulling apart the attached components. Performed experiments demonstrated that the use of this dismantling tool allows reducing the disassembly time for plastic housing components and PWBs of LED LCD TVs with respectively 36 % and 45 %. However, further analysis also demonstrated that the application of the tool has the following limitations:

- Sufficient distance between the two components to be separated is needed to be able to place the tool between the two components.
- The force that could be applied with the tool is insufficient to unfasten metal components connected by screws.

- Metal components connected by screws are often only deformed by the use of the tool while remaining connected.
- Housing components sometimes have to be pulled apart while repositioning the tool closer to the fasteners positioned in the centre of the product, which is impractical.

Because of these limitations, the authors believe that the developed dismantling tool can best be applied in specific cases for the dismantling of only plastic components and PWBs and this in combination with standard disassembly tools in either one or multiple dedicated working stations.

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